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**USE OF VISUAL METHODS FOR ESTIMATING FISH
ABUNDANCE AND HABITAT AREAS IN SMALL STREAMS**

Use of Visual Methods for Estimating Fish Abundance and Habitat
Areas in Small Streams¹

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I. Introduction

There is an increasing awareness among fishery biologists of the need to approach the planning and implementation of resource management programs and habitat enhancement projects from a basin-wide perspective. Biologists have generally employed one of two methods to generate a basin-wide perspective of fish production and habitat quantity: (a) extrapolation from "representative" reaches or "index" areas, or (b) systematic selection of equal length sections of stream. It has been generally assumed that either of these methods can provide accurate estimates of basin features such as total habitat areas and fish numbers.

Recent evidence has shown that use of "representative" reaches can result in generation of inaccurate and misleading notions of basin-wide conditions, however. For example, Everest et al. (1986) attempted to estimate the total amount of habitat and total fish numbers in Fish Creek, Oregon, by extrapolation from five "representative" reaches. A survey based on a statistically valid sampling design that ensures that all habitat types are sampled was carried out concurrently. Extrapolation from the "representative" reaches resulted in an apparent serious overestimation of total habitat area when compared to the statistically valid survey. Overestimation of total habitat area in turn led to overestimation of fish abundance. In another instance, Bisson (1988) estimated the number of fish in a small basin in Washington using different sets of "representative" reaches drawn from different portions of the stream. He found that estimated numbers of fish varied by several orders of magnitude depending on choice of "representative" reaches.

In this paper we present cost-effective sampling designs for estimating total habitat areas and total fish numbers in small streams based on visual estimation (Hankin and Reeves 1988). We consider practical application of these sampling designs in the field, and we also discuss procedures for construction of confidence intervals around calculated estimates. In addition to providing estimates of total habitat areas and fish abundance, use of these sampling designs can produce detailed maps showing the size, sequence of occurrence, and location of all stream habitat units. Data generated using these procedures may be used for identification of limiting factors and for inventory and monitoring purposes.

II. Estimating Total Habitat Areas

A. Classification of habitat units

This sampling design places substantial reliance on visual estimation of the areas of indentifiable habitat units. The first step in implementation of this design is therefore determination of what habitat unit types area of interest. We suggest use of definitions from Bisson et al. (1981) or those in the "Glossary of Stream Habitat Terms" (Habitat Inventory Committee, Western

Division of the American Fisheries Society 1985). Consistent definitions and criteria for classification of habitat unit types are vital to the success of a stream survey. Without such consistency, for example, it would be impossible to compare data collected by different observers in the same stream. Standardized definitions also allow comparison of habitat characteristics between streams.

Determination of the particular types of habitat units that are to be identified will depend on the purpose of a survey. Monitoring efforts usually require a more detailed classification of habitat unit types than general inventories. For basic inventory purposes it may be adequate to classify habitat types into very general categories such as pools and riffles. For detailed monitoring purposes, however, it may be necessary to define additional categories such as glides, side channels, and special types of pool units (e.g. break, lateral scour and plunge pools). Monitoring of enhancement efforts may be directed at a specific habitat type that is to be created. Regardless of the purpose of a survey, the types of habitat types that are of interest must be identified before the survey is initiated.

Prior to field work, all habitat characteristics that are to be measured should be identified. As for selection of habitat unit types, additional habitat characteristics to be measured will depend on survey purpose. The sampling design we describe below allows collection of a large amount of data at individual habitat units. Data generally collected included unit length, mean unit width, maximum unit depth, number of pieces of wood in given size categories, and dominant substrate.

B. Measurements at each unit

Two people are required for data collection for this method. One person (the "observer") is responsible for actual data collection whereas the other is responsible for data recording (the "recorder"). All visual or "eye" estimates described below should be made only by the observer.

The observer begins at the first habitat unit in a stream, identifies its habitat unit type, and then visually estimates its length, mean width, and area (length x mean width). Other habitat characteristics may also be measured or estimated. Points of reference, such as tributary junctions, road crossings, etc., should be noted by the recorder so that location in the basin can be better identified when the survey is completed.

As for definition of habitat units types, it is imperative that standardized criteria are followed for all measurements, visual or other. For example, it is often difficult to judge an appropriate length measurement for a pool that is irregularly shaped at one end. We have adopted the rule that the "end" of the pool is the midpoint between the point at which the pool becomes irregular in shape and the irregular endpoint of the pool.

In a systematic sample of units within a given habitat type, accurate measurements of unit characteristics are made in addition to visual estimates. For example, suppose one wanted to obtain accurate measurements of area in 10% of all pools in some reach of a stream (i.e. a sampling fraction of 10% is desired). The first unit to be measured should be determined by drawing a random number between 1 and 10 and making an accurate measurement of pool area in the pool that is selected. Then, accurate measurements of pool area should be made in every tenth pool thereafter. The initial "random start" might be 7, for example, in which case accurate measurements of pool area would be made in pool units 7, 17, 27, etc..

Selection of valid systematic samples for accurate measurements of habitat unit characteristics requires attention to two details. First, independent random starts should be drawn for each different classified habitat unit type. Second, once the initial random start has been selected for a given habitat unit type, then all subsequent accurate measurements must be made at exactly the same (systematic) interval between units. For example, suppose that the initial random start were 7 and that every tenth pool unit thereafter was to be accurately measured, as above. If field work on day "one" ended at pool unit 44, then the first pool unit for accurate measurements on day "two" should be pool unit 47, and subsequent units would be 57, 67, etc..

Accurate measurements of habitat unit areas should be made according to the following procedure: (a) measure unit widths at fixed 1-2 m intervals along the length of the unit and calculate the mean of these width measurements; (b) multiply mean width by total unit length to determine habitat unit area. Note that choice of interval between width measurements should depend on the complexity of a given habitat unit. A 2 m fixed interval may provide an accurate measurement of mean width in a broad, flat, straight riffle unit, whereas a 1 m interval may be required for accurate measurement of mean width in a complex, irregularly shaped pool unit.

If subsequent estimation of fish abundance is also to be carried out in the survey, the individuals responsible for collecting physical data should also mark and identify those units that will later be sampled for fish. The procedure for selection of units for fish sampling is described in part III of this paper. Both the lower and upper boundaries of these units should be marked with highly visible plastic flagging that has the unit type and unit number marked on it.

C. Data entry and storage

Use of this sampling design generally results in generation of large amounts of survey data. It is simplest to enter, store, and manipulate data in a computer spreadsheet such as LOTUS. [A spreadsheet will soon be available on the DG (Data General) system for U.S. Forest Service biologists.] Data for individual

habitat units should be entered on the computer in the same order in which units were encountered in the field survey (e.g. pool 1, glide 1, riffle 1, pool 2, glide 2, etc.). This procedure will retain the natural habitat unit location sequence for later mapping purposes, and the spreadsheet will allow easy sorting by habitat unit type regardless of order of data input. Most data manipulations and calculations associated with use of this sampling design can generally be carried out within the spreadsheet format.

D. Calculations and formulas

The basic premise of this method is that if visual estimates of habitat unit areas are highly correlated with accurate estimates of habitat unit areas, then one can "correct" for the possible bias of visual estimates through calculation of a "calibration ratio". The calibration ratio represents an estimate of the true ratio of true habitat unit area as compared to visually estimated area. This calibration ratio is calculated based on n paired visual and accurate estimates made in selected habitat units using

$$(1) \text{ Calibration ratio} = \hat{Q} = \frac{\sum_{i=1}^n m_i}{\sum_{i=1}^n x_i}$$

where m_i = true (accurately measured) area of unit i ;

x_i = visual estimate of area of unit i ; $i = 1, 2, \dots, n$

$\hat{Q}$ is an estimator of the true (but unknown) ratio of the actual area of all units compared to corresponding visual estimates of the areas of all units. (The carat or "hat" over Q is used to indicate an estimated quantity.) Calibration ratios should be calculated on the basis of no less than 10 (i.e. $n \geq 10$) paired accurate measurements and visual estimates for each habitat unit type. That is, separate calibration ratios must be calculated for pools, riffles or other habitat unit types. Note that the number of paired accurate measurements and visual estimates for a given habitat type will depend on (a) the total number of units of that type, and (b) the sampling fraction for that habitat unit type. If a particular habitat unit type is quite rare, a much larger sampling fraction will be required to achieve the minimum sample size of 10 units than if a particular habitat unit type is quite common.

Visual estimates of habitat unit areas do not necessarily need to be "close to" the true (accurate measurements of) habitat unit areas, but it is important that visual estimates have a consistent relationship to true habitat unit areas. For example, if all visual estimates were exactly half of true areas, then it would be a simple (and accurate) matter to adjust all visual estimates by a calibration ratio of 2 to arrive at very accurate estimates of habitat unit areas.

It is advisable to plot the relationship between accurate measurements of habitat unit areas and corresponding visual estimates of areas in addition to calculating the calibration ratio.

Visual inspection of plotted data points may reveal outliers or coding errors that might not be otherwise noticed. Also, it is a good idea to check that the plotted data appear to pass through the origin. If plotted data do not appear to pass through the origin, then the formulas presented below may be seriously biased. (Alternative regression estimators should be used in that case, but they are not presented in this paper.)

Once the calibration ratio has been calculated and plotted data have been visually inspected, the total area of habitat for a given habitat unit type (M) can be estimated using

$$(2) \quad \hat{M} = T_x \hat{Q}$$

where M = true total area of all units of a given type;

$$T_x = \frac{1}{N} \sum_{i=1}^N x_i = \text{total of visual estimates of area for all units of a given type;}$$

N = total number of units of a given habitat type

Equation (2) is a very natural and intuitive estimator, usually called a *ratio estimator*. Equation (2) states that the true total habitat area can be estimated as the product of (a) the total of the visual estimates and (b) the estimated ratio of true area to visual estimates of area.

A measure of the uncertainty of the estimated total area of a particular habitat type can be calculated from sample data using an estimator for the variance of equation (2). The variance of

the estimated total, denoted by $V(\hat{M})$, can be estimated using

$$(3) \quad \hat{V}(\hat{M}) \approx \frac{N^2(N-n)}{Nn} \sum_{i=1}^n (m_i - \bar{Q}x_i)^2 / (n-1)$$

Equation (3) is a large sample approximation for the variance of a ratio estimator and it may seriously underestimate the uncertainty of the estimated total habitat area if $n < 10$. For that reason, we recommend that $n \geq 10$.

Examination of equation (3) reveals that variance depends on two very different kinds of terms. First, variance (uncertainty) will be reduced simply as a function of sample size through the term $(N-n)/Nn$. As sample size, n , approaches the total number of units, N , clearly variance approaches zero. Thus, the sampling fraction (n/N) will influence variance. Second, the summation term essentially consists of squared differences between (a) true (accurate measurements of) habitat unit areas, m_i , and (b) pre-

dicted habitat unit areas, $\hat{Q}x_i$. If accurate estimates and visual estimates are highly correlated, and a plot of accurate estimates against visual estimates appears to pass through the origin, then

these squared differences will be small so that estimated variance will be small. In contrast, if visual estimates are inconsistently related to accurate measurements, then predictions of true habitat areas from visual estimates will be poor, squared differences will be large, and estimated variance will be large.

The strong dependence of estimator variance on a consistent relationship between true habitat unit areas and visual estimates of habitat areas makes it especially critical that observers follow a consistent technique in making their visual estimates. Carefully pacing off units at approximately 5 m increments requires substantial concentration and we recommend that our observers take periodic breaks to relax rather than making poor or inconsistent visual estimates of habitat areas. This requirement for consistency is also behind our recommendation that just a single observer be responsible for all visual estimates.

The total area of all units of all identified habitat types in a stream can be estimated simply by summing up individual estimates for individual habitat types (or individual habitat types within a particular reach of stream). Estimated variances are also additive because estimates of total habitat areas of particular habitat unit types are independent of one another (since they are based on entirely separate sample data).

Finally, approximate 95% confidence intervals for estimated total areas of habitat units can be constructed as

$$\bar{M} \pm 2 \cdot [\bar{V}(\bar{M})]^{0.5}$$

Table 1 presents results of application of this sampling design in a small Oregon coastal stream, Cummins Creek. In the Cummins Creek application, the stream was first stratified into a lower and a middle/upper reach. Sampling fractions were 10% (1 out of 10) in the lower reach and 5% (1 out of 20) in the middle/upper reach. Use of this method in Cummins Creek produced 95% confidence bounds for estimated total areas of pools and riffles that were about 13% and 16% of estimated totals, respectively.

E. Maps of habitat unit locations and sizes

Besides providing estimates of the total areas of particular habitat unit types, often with very small confidence intervals, this sampling design allows the construction of detailed maps of the locations and areas of all habitat units. Such maps could be used to compare habitat unit areas and sequences between seasons or years, or to evaluate the effects of various habitat alterations.

F. Costs

We estimate that it costs from \$80 - \$100 per mile to survey small basins using this technique. This cost estimate includes costs of (a) data collection, (b) computer data entry, and (c)

Table 1. Total number of units (N), number of units accurately measured (n), sample-based estimates of ratios of accurately measured areas to visually estimated areas ($\bar{Q}$), estimated total areas ($\bar{M}^2$) of all units ($\bar{M}$), estimated variances for estimated total areas ($\bar{V}(\bar{M})$), and 95% confidence bounds for estimated total areas (95% C. I.) for pools and riffles in lower, middle/upper, and all reaches combined of Cummins Creek during July 1985.

Visual estimates of habitat unit areas were made for all units.

(from: Hankin and Reeves 1988)

Pools

Reach	N	n	$\bar{Q}$	$\bar{M}$	$\bar{V}(\bar{M})$	95% C. I.
Lower	65	7	0.990	6,141	119,827	± 875
Middle/ Upper	134	6	1.029	8,284	448,315	$\pm 1,721$
All Reaches				14,425	568,142	$\pm 1,938$

Riffles

Lower	62	6	1.066	12,556	159,155	$\pm 1,026$
Middle/ Upper	124	7	0.926	19,208	3,846,554	$\pm 4,799$
All Reaches				31,764	4,005,709	$\pm 5,146$

data analysis. The cost will of course vary with crew experience, basin size, and the number of habitat unit types identified. In most systems, an experienced crew can cover 4-6 stream miles per day. Interestingly, larger systems may often be covered more quickly than smaller systems because habitat units are larger so that there are fewer per stream mile. Finally, the general requirement that sample sizes exceed 10 for each distinct habitat unit type means that large numbers of distinct habitat unit types will require a large number of accurate (and more costly) measurements of habitat areas.

G. Review of Procedures (* denotes optional procedure)

(1) Prior to field work:

- a. Determine the types of habitat units that are to be identified.
- b. Determine habitat unit characteristics that are to be measured or estimated at each unit.
- c. Determine sampling fractions ($1/k$) for each habitat unit type (this will determine the number of units for which both accurate and visual estimates of habitat unit area are made).
- d. Given prespecified values for k , which may differ between habitat unit types, choose independent random starts on the interval 1 through k for each distinct habitat unit type.
- *e. If necessary or desirable, stratify basin into different areas or reaches on the basis of stream gradient or other distinctive feature(s). These different areas or reaches will constitute distinct location strata and should each be independently sampled.

(2) Field work:

- a. Observer begins at first habitat unit, identifies its type, and collects necessary data. Observer makes visual estimate of habitat unit area for every identified habitat unit. Points of reference are noted by data recorder.
- b. At the unit selected by the random start within each identified habitat type, and at every k units thereafter, the observer makes a visual estimate of habitat unit area, and the two person team makes an accurate estimate of habitat unit area.
- *c. If necessary, observer marks units which are to be later sampled for fish. Units should be marked with highly visible flagging at the upstream and downstream ends of these units and flagging should have unit type and unit number written on it.

(3) Data entry and analysis:

- a. Data are entered into spreadsheet in the natural order in which units were encountered in field work.

- b. Distinct calibration ratios are calculated for each identified habitat unit type using equation (1).
- c. Totals areas, associated variances and confidence intervals are calculated for each identified habitat unit type using equations (2) and (3).

III. Estimating the total number of fish

A. Selection of units

It is obviously impractical to estimate the total number of fish by sampling every stream habitat unit. Instead, we recommend selection of a systematic sample of habitat units (from within each habitat type), following those procedures presented for selection of units for accurate measurements in part II.B. Systematic selection of units does not require a preexisting map of the locations of all habitat units nor does it require knowledge of the total number of units of each habitat type. In addition, systematic samples will ensure that sample data are collected along the entire longitudinal gradient of the basin. As for units selected for accurate measurements of habitat areas, sampling within each distinct habitat unit type must begin with an independent random start.

The fraction of the units that are sampled need not be the same for every habitat type and may depend on unit type, fish species and habitat preferences as well as available time, funds and personnel. It is usually, but not always, best to have higher sampling fractions for those habitat types that appear to be preferred by the species of interest. For example, if the species of interest were 1+ juvenile steelhead trout or coho salmon, then pools should probably have a higher sampling fraction than riffles or glides. In this case one might sample 25% of all pools, 15% of all glides and just 10% of all riffles. It is extremely important to remember that all habitat unit types must be sampled even if fish are not "believed" present in some habitat types. There is only one method by which their absence in that habitat type may be verified: collection of sample data for that habitat type.

Units which are to be sampled for fish should have been previously marked by the two person team responsible for physical habitat measurements. Plastic flagging or other markers with unit type and number should have been placed at the upper and lower boundaries of selected units. If visual counts of fish are to be made by divers in selected units, then it is best to have a minimum of two hours between the time the units are marked and when they are actually snorkled. This delay should be sufficient to minimize any effects of disturbance on fish in habitat units.

B. Sampling fish populations

Estimation of fish numbers relies on essentially the same premise as estimation of habitat areas. If divers count a fairly consistent fraction of fish actually present in habitat units, then there should be a strong correlation between diver counts and the "true" (accurate estimates of) numbers of fish present. In this case visual estimates are made by divers using mask and snorkel and "accurate" estimates are made using a multiple pass electrofishing removal method estimator. By calculating a calibration ratio relating these accurate estimates to diver counts, based on a small sample of units in which both visual estimates and accurate estimates are made, one may "adjust" diver counts to estimates of true abundance in those units in which only visual estimates are made.

A team of two divers is used to count fish. Divers enter the water downstream from the selected unit and proceed slowly upstream. The divers position themselves near the midline of the unit and move parallel to one another using hand signals to coordinate their movements. Observed fish are identified to species or species/age class and counted. Fish counts are recorded with a lead pencil on a plexiglass slate that has had the surface roughened with sandpaper. Observations should all be made during times of day when visibility is best, generally between 0900 and 1700.

Correlations between diver counts and accurate estimates will generally vary with species, age-class and habitat type. For example, we found higher correlations between diver counts and accurate estimates for coho salmon in pools than for 1+ steelhead trout in pools (Hankin and Reeves 1988). These differences were attributable to differences between the two species in microhabitat distribution and behavioral responses to divers. Trout were closely associated with the bottom, whereas coho salmon were more surface-oriented and were thus easier to see. Trout were also more "skitterish" and sought cover more quickly than salmon, especially in smaller units. Because of these differences, divers scanned the bottom immediately upon entering units and counted trout before salmon.

Use of snorkeling to count fish has obvious limitations which may make it impractical for use in some situations. Water clarity is critical, the method is most effective in small streams, and there are generally limited numbers of individuals who are highly trained and skilled in this method of observation. We are currently exploring alternatives to snorkeling, but we have not yet developed any sound alternatives.

Of those units in which diver counts of fish numbers are made, we select a random subsample within which both diver counts and more accurate estimates are made. The theory of this method requires that the "accurate" estimates of fish abundance be equal to the "true" but unknown numbers of fish present. It is therefore extremely important that accurate methods produce

estimates of fish numbers that have very small confidence intervals.

C. Data entry and storage

Data on diver counts and accurate estimates made for selected units can be entered in the spreadsheet format in the same manner as those for physical habitat measurements. Additional computer programs may be necessary for estimation of population size for the "accurate" estimation method, however.

D. Calculations and formulas

A "calibration ratio" establishing the correspondence between accurate estimates (true numbers) of fish present, y_j , and diver counts, d_j , within a given habitat type may be calculated using

$$(4) \quad \bar{R} = \left(\frac{\sum_{j=1}^{n'} y_j}{\sum_{j=1}^{n'} d_j} \right)$$

where: y_j = true number of fish in unit j ; $j = 1, 2, \dots, n'$
(estimated by use of a very accurate method);

d_j = mean count of fish by two divers in unit j ;

n' = number of units in which both diver counts and accurate estimates are made.

As for estimation of habitat areas, distinct calibration ratios must be calculated for each habitat type and there should be a minimum of ten units within each habitat type for which both diver counts and accurate estimates are made (i.e. $n' \geq 10$).

Ideally, the units selected for accurate estimates in addition to diver counts should be a simple random or systematic subsample of those units in which diver counts are made. Occasionally, however, it may prove impractical or impossible to carry electrofishing equipment into some selected units. In that event, units reflecting the full range of size and complexity of those units found in the system should be included in the sample of size n' .

For units in which only diver counts have been made, the calculated "calibration ratio" allows adjustment of diver counts to give a better estimate of the true number of fish actually present. (Divers may only count half the fish that are actually present, for example, in which case the true calibration ratio would be 2.) The numbers of fish present in such units can therefore be estimated as the product of the mean diver count and the estimated calibration ratio using

$$(5) \quad \bar{y}_1 = R \bar{d}_1$$

where: R = calculated calibration ratio (equation (4));

$\bar{d}_1$ = mean of two diver counts in unit 1.

If the total number of units in which diver counts are made is defined as n , and the total number of units in which both diver counts and accurate estimates are made is defined as n' , then there will in general be $(n-n')$ units in which fish numbers will be estimated using equation (5). In the remaining n' units, the "accurate" method of estimating fish numbers eliminates the need to use equation (5); the accurate estimates should be used for these units.

Finally, the total number of fish present in all units of a given habitat type may be estimated using

$$(6) \quad \bar{Y} = N \sum_{i=1}^n \bar{y}_i / n$$

where: Y = (true) total number of fish in all units of a given habitat type;

N = total number of units of a given habitat type;

n = total number of units in which diver counts are made; $i = 1, 2, \dots, n$.

Equation (6) is simple and intuitive. It basically consists of multiplying the mean estimated number of fish per habitat unit ($= \sum \bar{y}_i / n$) by the total number of habitat units ($= N$).

In some streams, the number of fish present in habitat units may be highly correlated with the sizes of habitat units. In that case, equation (6) will not give the best estimate of total fish abundance. Hankin (1984, 1986) discusses alternative estimators that will perform better than equation (6) if fish numbers are highly correlated with habitat unit sizes.

A measure of uncertainty for the estimated total number of fish in a given habitat type may be calculated using the following estimator for the variance of equation (6):

$$(7) \quad \hat{V}(\bar{Y}) = \frac{N(N-n)}{n(n-1)} \sum_{i=1}^n (\bar{y}_i - \bar{y})^2 + \frac{N}{n} \sum_{i=1}^n \hat{V}(\bar{y}_i)$$

where: N = total number of units of a given habitat type
 n = total number of units in which diver counts are made

$\hat{y}_i$ = estimated number of fish in unit i ; $i = 1, 2, \dots, n$

$\bar{y} = \sum_{i=1}^n \hat{y}_i / n$ = mean estimated number of fish per habitat unit.

and $\hat{V}(\hat{y}_i)$ = estimated variance of the estimated number of fish in unit i

$\hat{V}(\hat{y}_i)$ represents errors of estimation of fish numbers in individual habitat units. It may be assumed equal to zero for those units in which very accurate estimates are made or, alternatively, may be calculated on the basis of formulas appropriate for removal method estimation using electrofishing. (Remember that there are n' out of n units in which the accurate estimates have been made.)

For those units in which only diver counts are made (there are $n - n'$ such units), $\hat{V}(\hat{y}_i)$ will depend on (a) variation between the two diver counts made in those units and (b) variance of the estimated calibration ratio relating accurate estimates to diver counts.

Between diver variance is denoted by $\hat{V}(d_i)$ and is estimated using

$$(8) \quad \hat{V}(d_i) = \frac{1}{2} \sum_{k=1}^2 (d_{ik} - d_i)^2$$

where: d_{ik} = count of fish by diver k in unit i ; $k = 1, 2$

$$d_i = \sum_{k=1}^2 d_{ik} / 2 = \text{mean diver count in unit } i$$

i = unit in n but not in n'

Variance of the estimated calibration ratio is calculated using

$$(9) \quad \hat{V}(\hat{R}) = \frac{(N - n')}{Nn' \bar{d}^2} \sum_{i=1}^{n'} (\hat{y}_i - R d_i)^2 / (n' - 1)$$

where: $\bar{d} = \sum_{i=1}^{n'} d_i / n' = \text{"grand mean" diver count}$

Note that the summation in equation (10) is over the n' units for which paired diver counts and accurate estimates were made.

Finally, for those $(n-n')$ units in which only diver counts have been made, variance of the estimated number of fish in such units can be calculated using

$$(10) \quad \hat{V}(\hat{y}_1) = \hat{R}^2 \hat{V}(d_1) + d_1 \hat{V}(\hat{R}) - \hat{V}(d_1) \hat{V}(\hat{R})$$

These values would then be substituted in equation (7), above.

Although of complicated forms, the above formulas for calculating the variance of an estimated total number of fish in a given habitat type can be separated into two distinct parts. One component of variance arises due to what statisticians term first stage variance. If there were no errors of estimation of fish numbers within selected habitat units, but only a sample of n habitat units were selected from a total of N habitat units, there would be errors of extrapolation from the sample units to all of the units. These errors result from variation in the true numbers of fish between habitat units. If, for example, each unit had exactly the same number of fish, then there would be no variation in fish numbers between units and, as a result, first stage variance would equal zero. In contrast, if true fish numbers were highly variable across habitat units, then first stage variance would be large.

Most fishery biologists are not very familiar with the concept of first stage variance, but they are very familiar with what statisticians term second stage variance. Second stage variance reflects errors of estimation of fish numbers within selected units. If every habitat unit were sampled, then all of the errors of estimation would come from this stage of sampling since no extrapolation would be involved. Mark-recapture or removal method estimators of population size will in general result in smaller second stage variance than "calibration" of diver counts.

In our experience with sampling streams, first stage variance usually is a much more important source of error of estimation than is second stage variance. Also, if numbers of fish present in habitat units are poorly correlated with the sizes of habitat units, then first stage variance can only be reduced by sampling a large fraction of all habitat units. The use of divers for visual estimates of fish numbers in habitat units allows one to greatly increase the total number of units that are sampled for fish. Although this usually results in slightly greater errors of estimation of fish numbers within units (second stage variance), the substantial reduction in first stage variance that results more than compensates for these minor additional errors. To put it more simply, one makes a modest sacrifice of accuracy within individual habitat units to obtain a dramatic increase in accuracy of estimation of fish numbers in all habitat units.

Table 2 illustrates the results of applying these methods for estimation of juvenile coho salmon and 1+ steelhead trout numbers in pools and riffles of Cummins Creek. Diver counts were made in approximately 20% of all units and paired diver counts and exhaustive electrofishing/removal method estimates were made in about 8 units of each habitat type. Confidence bounds (not reported on Table 2) for the total abundance of salmon and trout in all pool and riffle units combined were approximately 22% and 17% of the estimated totals, respectively.

E. Costs

We have not determined the average costs of sampling fish populations using this sampling design. However, we have compared the probable performance of this design with a more typical stream survey that might be carried out exclusively using electrofishing methods for estimation of fish numbers in selected habitat units (Hankin and Reeves 1988). For the same total cost of sampling, we found that our visual estimation survey (with calibration) would result in variances that were from 1.7 to 3.3 times smaller than those that would be achieved in the more standard survey (electrofishing only). That is, for the same total survey cost, the visual estimation design was from 1.7 to 3.3 times as cost-effective. For the typical survey, fewer units can be sampled if only electrofishing is used to estimate fish numbers in selected habitat units. Although diver counts may be less accurate than electrofishing, divers can count fish much more rapidly and can therefore examine a much larger number of habitat units. This increased coverage of habitat units in turn leads to a substantial reduction in first stage variance and in total errors of estimation.

F. Review of procedures (* denotes optional procedure)

(1) Before field work:

- a. Determine types of habitat units that are to be identified.
- b. Determine sampling fractions for visual estimates of fish numbers for each habitat unit type. (These may differ with habitat unit type.) Select independent random starts for each habitat unit type. Units selected by these random starts should be marked by the team collecting physical data (Part II) as should subsequent units that appear in systematic samples drawn from each habitat type.
- c. Determine approximate subsampling fraction for which both visual estimates and accurate estimates will be made. Select appropriate random starts for selection of these units from those selected and marked in (1)b.
- *d. If necessary or desirable, stratify basin into different areas or reaches on the basis of gradient changes or other distinctive features.

Table 2: Estimated abundances ($\bar{Y}$) of 1+ steelhead trout and juvenile coho salmon, total number of habitat units (N), sample sizes for diver counts (n), and estimated variances of abundance estimates ($\bar{V}(\bar{Y})$) in lower, middle and upper pools and riffles and in all pools, all riffles and all pools and riffles, in Cummins Creek, July, 1985. (from: Hankin and Reeves 1988).

Habitat Type/ Location Stratum	N	n	<u>Coho Salmon</u>		<u>Steelhead Trout</u>	
			$\bar{Y}$	$\bar{V}(\bar{Y})$	$\bar{Y}$	$\bar{V}(\bar{Y})$
Lower pools	65	11	2,111	112,769	1,480	21,185
Middle pools	67	13	1,088	36,024	738	17,205
Upper pools	67	12	101	1,266	428	13,943
All pools			3,300	150,059	2,646	52,333
Lower riffles	62	10	576	40,407	527	24,505
Middle riffles	67	13	230	5,588	236	4,967
Upper riffles	57	9	0	0	0	0
All riffles			806	45,995	763	29,472
All pools and all riffles			4,106	196,054	3,409	81,805

(2) Field work

- a. Divers proceed to unit selected as random start for each habitat type and count fish numbers in that unit and in subsequent units that appear in systematic samples. Record unit numbers and fish counts (individually) on data sheets as appropriate.
- b. For units selected in (1)c above, use a multiple pass electrofishing removal method estimator to obtain an accurate estimate of true fish numbers in these units. (Diver counts are also made in these units).

(3) Data entry and analysis

- a. Enter collected data in spreadsheet as for physical habitat data.
- b. Calculate calibration ratios for each distinct habitat unit type, using equation (4).
- c. Estimate true numbers of fish present in those units for which only diver counts are available using equation (5).
- d. Estimate the total number of fish in all units of a given habitat type using equation (6).
- e. Calculate variance estimates using equations (7) - (10).

IV. Literature Cited

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